METEOROLOGICAL INVESTIGATIONS WITH THE AID OF ARTIFICIAL EARTH SATELLITES

I. P. Vetlov

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I. P. Vetlov
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The date of 4 October 1967 marked the tenth anniversary of the launching of the first artificial earth satellite by the Soviet Union. An even shorter period of time has passed since the beginning of studies in the use of satellites for meteorological purposes. During this brief interval, satellite meteorology has undergone very rapid development and has attracted the attention of many researchers in various fields. There has been intense development of methods of measurement, and of apparatus for obtaining various types of data, important for the analysis and forecasting of weather, with the aid of satellites. Numerous studies have likewise been devoted to working out methods of analysis, interpretation, and practical utilization of satellite observations. As a result of satellite launchings, material has been gained for further expansion of these studies and for the improvement of the satellites themselves. At the same time, experience has been gained in the actual application of satellite data to the analysis and forecasting of the weather. Methods of synoptic analysis using satellite data are having a considerable influence at the present time on the entire system of the weather bureau's informational and prognostic activity.

The visual observations of Soviet cosmonauts and the photographs of the cloud cover which they obtained have been of considerable significance in the development of meteorological investigations with the aid of artificial earth satellites. Even the initial visual observations made by the cosmonauts were indicative of the broad possibilities for the use of satellites in meteorology. The photographs of the cloud cover which they obtained made it possible to discern many details of the distribution of air-mass convective clouds and the structures of multistage, large-scale cloud systems, related to cyclones and atmospheric fronts. Observations of optical phenomena in the atmosphere made by the cosmonauts were also very valuable for research purposes.

The insufficiency of basic data required for the successful functioning of the weather bureau and the development of meteorological studies aroused considerable interest on the part of meteorologists in the use of satellites. The network of observation sites in many sparsely populated land areas and over the immense watery expanse of the Pacific Ocean (which covers a total of about 80% of the surface of our planet) is so sparse that it fails to provide a true picture of the nature of the weather over vast territories. Even in densely populated regions, where weather stations are located 60 to 100 km apart, the discreteness of terrestrial observations may result in a failure to detect certain details of the formation and development of weather phenomena.

The lack of complete information on the scale of the entire globe causes particular difficulty with regard to the meteorological aspects of aircraft flights along intercontinental routes, and of the navigation of the vessels in the merchant marine and fishing fleets, which operate on practically all oceans.

Global meteorological observations are particularly necessary for the study of the features of atmospheric processes under diverse physical and geographic conditions, and for the investigation of the nature of their interaction in the system of the general atmospheric circulation, for the purpose of developing methods of long-range weather forecasting.

The establishment of a dense network of observation sites everywhere on the continents, together with a significant increase in the number of weather ships on the seas and oceans, would entail considerable material expenditure. Moreover, even if the governments of all countries did build a very dense system of interconnected stations, such a system could not be used very effectively due to the difficulties in the practical collection and analysis of the enormous volume of data gathered from points scattered over the entire planet. In addition, the use of conventional technical means does not permit regular information to be obtained regarding the amount of radiant energy in various segments of the electromagnetic wave spectrum which is lost to space and which remains in the atmosphere. In order to obtain this information, which is important for the study of the atmosphere and the processes occurring in it, it is necessary to measure the radiation currents passing through the uppermost layer of the atmosphere, i.e., at very great heights from the practical point of view.

Modern achievements in the field of space research indicate that the use of artificial earth satellites opens up broad opportunities for improving the function of the weather bureau and expanding meteorological investigations. Artificial satellites used specifically as carriers for various types of scientific apparatus can make it possible to obtain regular information regarding the atmosphere and the subjacent surface over the entire planet, uniformly describing the entire globe in terms of meteorological data. Since they make it possible to scan large areas from above in a short period of time and then transmit the observational data to receiving stations, satellites are also capable of making the collection of meteorological information more practical.

In recent years, methods have been proposed for using satellites to obtain a great many different types of meteorological data. The following are of primary interest in the analysis and forecasting of the weather:

(a) Distribution of clouds, snow cover, and ice fields.

(b) The temperatures of the subjacent surface and the upper layer of clouds.

(c) Components of the radiation balance of the Earth-atmosphere system.

(d) Vertical distribution of temperature and humidity in the atmosphere.

(e) Zones of precipitation, their intensity, distribution of storm clouds, etc.

With suitable measurement accuracy, these data which have been collected from the entire globe serve to supplement and expand considerably the materials from conventional observations. On the basis of known regularities and relationships, they make it possible to determine the state and modification of other meteorological elements, which cannot be measured directly from satellites. Their joint analysis with data from terrestrial observations can serve as the basis for preparing weather reports and forecasts for many users.

The most important problem facing space meteorology today is that of forming a constantly operating system for meteorology in space, one which would make it possible (by means of artificial earth satellites) to have regular reception of a wide range of meteorological data on a planetary scale, and one which would satisfy the requirements of the weather bureau with regard to accuracy, periodicity, spatial resolution and synchronization of observations, and the speed with which the information could be sent to the organizations interested in it. The design of such a system requires the solution of a great many theoretical, experimental-designing and testing problems. Considerable energy must be devoted to the development of apparatus on board the satellite which would ensure reliable meteorological observations as well as long-term operation of the satellites in interplanetary space. The outlook for the use of satellites for meteorological purposes depends primarily on the successful solution of this problem.

The volume of information arriving from all over the world via the satellites in such a system will be extremely great, and the problem of its practical analysis can be solved only by the use of highly efficient electronic computers and various automatic devices. This brings up the important problem of building an automatic system for receiving and analyzing satellite information. This means that meteorologists will have to learn not only how to analyze and correctly interpret qualitatively new data arriving from satellites, but will also have to use them effectively in analyzing and forecasting the weather. The practical use of the vast amount of material which will result from the analysis of the satellite observations will also require expansion and improvement of communications media.

In order to solve the numerous scientific and technical problems related to the construction of a constantly moving meteorological system, it is necessary to acquire experience in using meteorological satellites and to collect material for further investigations.

Acting on this assumption, those in the USSR who have worked on the scientific research and designing problems related to the meteorological utilization of satellites have devoted themselves initially to developing an experimental meteorological system for use in space, which is intended for obtaining meteorological information for the weather bureau and for analyzing problems of meteorological investigations with the aid of satellites.

It was decided to build an oriented satellite, carrying out a broad program of meteorological observations, for use in the experimental system. The apparatus aboard it included instruments for simultaneous detection of cloud formations, snow and ice cover in the visible and infrared regions of the spectrum, measurement of outgoing radiation in order to determine the temperatures of clouds and the subjacent surface, and the components of the radiation balance of the Earth-atmosphere system. This assembly of scientific apparatus was tested aboard the "Cosmos 122" satellite, which was launched on 25 June 1966. At the same time, when this satellite was launched, the operation of various control systems on board was tested, along with the checking of terrestrial facilities for receiving and analyzing the meteorological information.

The "Cosmos 122" satellite, which was successfully placed in orbit for a period of 4 months, carried out daily meteorological observations above different regions of the globe. During this time, the satellite made it possible to obtain a large volume of observational data in the form of photographs of the cloud cover on the day and night sides of the Earth, as well as the results of measurements of the outgoing radiation. These data were of great value for both the scientific research programs and the practical operation of the weather bureau. Therefore, after the methods of analysis had been tested, the most important ones were distributed to the subdivisions of the Hydrometeorological Service of the USSR and the meteorological services of other countries.

The next step in the project came with the launchings of the "Cosmos 144" and "Cosmos 156" meteorological satellites (on 28 February 1967 and 27 April 1967, respectively). Both of these satellites were placed in low circular orbits, passing 625 to 630 km above the Earth's surface and inclined at 81.2° At the end of August 1967, the "Cosmos 144" satellite had completed 2700 revolutions around the Earth. During this time, there were 464 sessions involving photography of the cloud cover on the side of the planet illuminated by the Sun, and 577 operations of the apparatus for photographing the cloud cover on both the day and night sides of the Earth. On the whole, during six months of operation, the transmitters mounted aboard the "Cosmos 144" viewed the entire globe 65 times and sent back an immense amount of information on cloud cover and radiation currents. When the "Cosmos 156" satellite was placed in orbit, the event marked the beginning of construction of an experimental meteorological system in space, called "Meteor", consisting of orbiting meteorological satellites in the "Cosmos" series and a network of ground stations for the reception, analysis and transmission of the meteorological information from the satellites.

The "Meteor" system consisting of two satellites ("Cosmos 144" and Cosmos 156") makes it possible to obtain information on cloud cover and outgoing radiation from half of the surface of our planet in the course of 24 hours. The results of the analysis of this information are widely employed in the daily work of the forecasting sections of the Hydrometeorological Service of the USSR. At the same time, they are regularly available for international exchange.

The meteorological investigations with the aid of artificial earth satellites which have been carried out in our country in recent years have also included experiments in receiving television pictures of the cloud cover from the communications satellite "Molniya 1". These experiments are of interest from the standpoint of examining the virtues of using high-orbital satellites in a continuously operating meteorological system in space.

On the whole, taking into account the important position and tremendous promise for the use of satellites in meteorology, the present era must be viewed as a preliminary stage in the construction of a system which will satisfy the requirements of the weather bureau.

Scientific Apparatus Aboard the "Cosmos" Meteorological Satellite

From the standpoint of design, the "Cosmos" meteorological satellite is a cylindrical container with two panels carrying solar batteries; the latter unfold after the satellite separates from the carrier rocket (Figure 1). The lower part of the container houses the instrument section, where the scientific apparatus is located, while the upper part is the power apparatus section, in which the principal control systems are located.

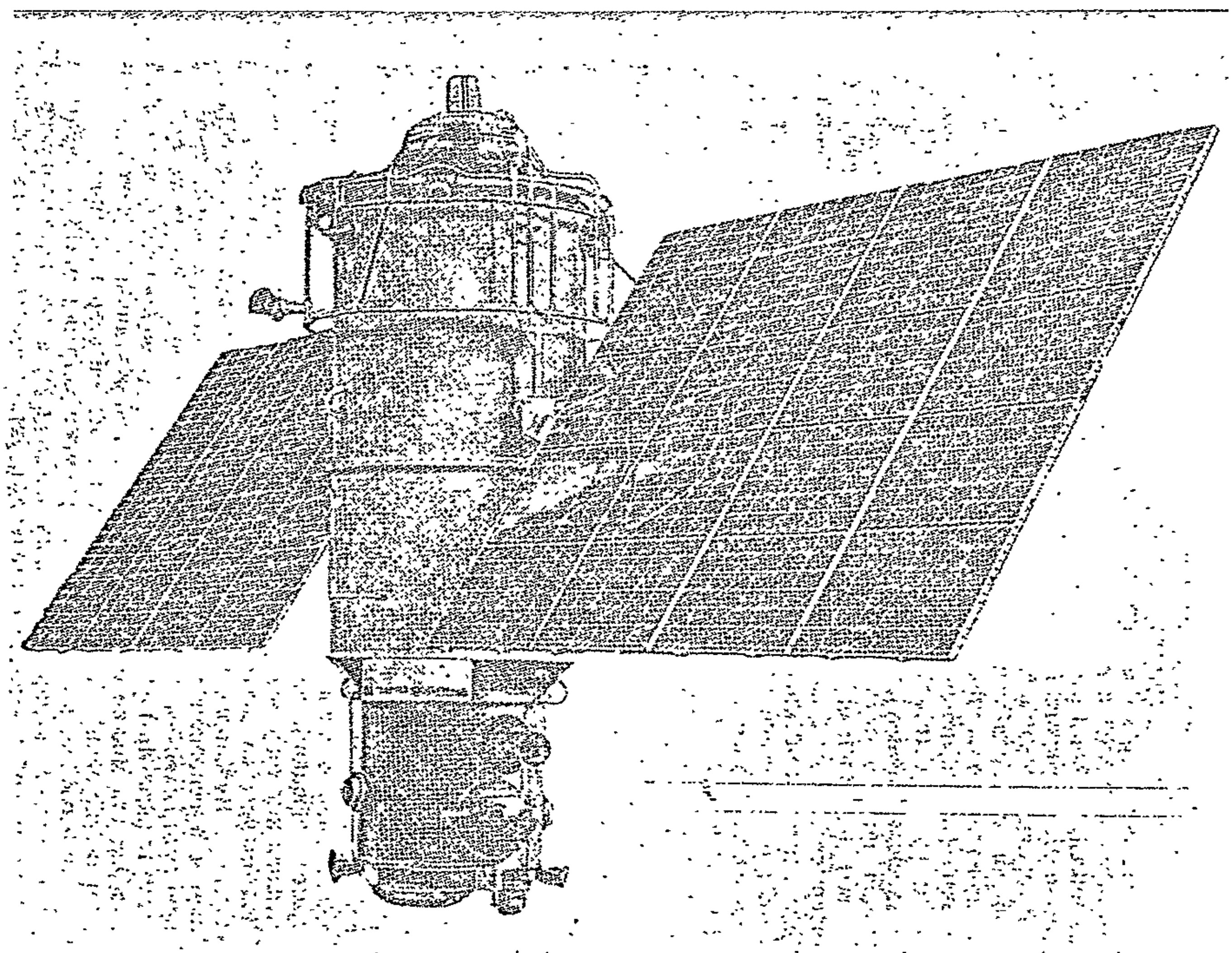

Figure 1. "Cosmos 144" Artificial Earth Satellite

The control equipment of the satellite includes various electronic and radio-controlled systems which automatically take care of the following: the electrical supply to the apparatus on board, and creation of conditions necessary for its normal function: orientation and stabilization of the satellite's position in space; recording observational results and their transmission to Earth; control of all systems on board and monitoring of their function; radio observation of the satellite and measurement of its motion parameters; relating of meteorological and control information to time.

It is very important for the meteorological apparatus that there be constant orientation of the instrument section of the satellite housing toward the Earth (more precisely, along the local vertical to the nadir) and along a given course (speed vector); this is ensured in flight by a heavy-duty system of triaxial orientation. Stabilized orientation of the instrument container toward the Earth and along the course makes it possible to carry out observations directly below the satellite while carrying out an uninterrupted program of measurements, and it also simplifies the matching of the results of the observations with the location, as well as their interpretation.

To ensure uninterrupted operation of all satellite systems, its solar batteries, which constitute the power supply for all the apparatus on board, are automatically oriented toward the Sun.

A television apparatus (TV) is used for observations of the cloud cover on the day side of the Earth. This device uses two cameras to take frame-by-frame pictures of the cloud cover and the subjacent surface along the route of the flight. One camera photographs the left-hand side of the field of view and the other photographs the right-hand side; there is a slight overlapping of adjacent frames. In determining the parameters of the TV apparatus, the problem arose of obtaining TV pictures that would give information about the shape and number of clouds in areas commensurate with the dimensions of basic synoptic objects (cyclones, anti-cyclones, atmospheric fronts, etc.). Taking the peculiarities of the structure of the cloud field into consideration, the TV cameras were constructed in such a way to solve this problem that from a height of 600 to 700 km the width of the scanned strip is 1000 km, and the spatial resolution of the images is 1.25 x 1.25 km at the nadir.

An infrared apparatus (IR) of television type, sensitive to the radiation current in the "transparent window" of the atmosphere (8 to 12 microns), is used for observing the cloud cover on the night side of the Earth. The maximum of the radiation emitted by the Earth's surface and the clouds is concentrated in this portion of the spectrum, and its value is determined mainly by the temperature of the radiant surfaces; at the same time, there is practically no reflected solar radiation. With the aid of this IR apparatus, therefore, it is possible to detect clouds against the background of the Earth's surface by their lower values of outgoing radiation, on both the night and day sides of the Earth.

To obtain an image, the scanning mechanism of the IR device makes a scanning motion in a plane perpendicular to the plane of the orbit, successively scanning one section after another of the selected field of view. The scanning period is set so that a continuous image is obtained along the field of view. For analysis of a cloud field, the width of the scanned strip examined by the IR apparatus is set approximately equal to 1000 km. Its spatial resolution amounts to 15 x 15 km at the nadir, while the sensitivity to temperature drops is 2 to 3° at positive temperatures and 7 to 8° at negative ones.

The outgoing radiation is measured by an actinometric apparatus (AK), consisting of two scanning narrow-sector and two non-scanning wide-sector devices whose field of vision encompasses the entire disk of the Earth as visible from the altitude of the satellite. One of the narrow-sector devices measures the intensity of the outgoing radiation in the spectral range from 0.3 to 3μ, while the other operates in the spectral range from 3 to 30μ, with scanning in one direction, and 8 to 12μ, with scanning in the opposite direction. The selection of these spectral ranges was based on the fact that the major portion of the energy in the flow of solar radiation lies in the spectral range from 0.3 to 3μ, while the natural thermal radiation from the Earth's surface, the clouds, and the atmosphere is almost completely restricted to the 3 to 30μ region of the spectrum. Hence, the measurement results in these areas of the spectrum can be used to study the reflecting and radiating properties of clouds and exposed areas of the Earth's surface, respectively, as well as to determine the components of the radiation balance of the Earth-atmosphere system. Measurements in the spectral range from 8 to 12μ, in which the atmosphere exhibits weak adsorption of the outgoing radiation, make it possible to determine the temperature of the upper limit of the clouds and of the exposed portions of the subjacent surface, located within the field of vision of the apparatus.

Simultaneously with the determination of the parameters of the narrow-sector AK instruments, the problem arises of obtaining data suitable for joint analysis with ground observations and for refinement of the analysis of the TV and IR pictures of the cloud cover. On the basis of the density of the existing network of meteorological stations, the spatial distribution of these devices was taken as equal to 50 x 50 km at the nadir. The working angle of their scan was set at ± 60° from the direction of the nadir, thus making it possible to ensure sweeping a belt of terrain approximately 2500 km wide.

The flow of outgoing radiation is measured in the spectral ranges from 0.3 to 3μ and 3 to 30μ by means of the wide-sector AK instruments, which directly sum the radiation over a large area. The results of these measurements, as well as the measurement data from the narrow-sector instruments, make it possible to determine the planetary distribution of the radiation balance. In the first case, however, reliable determination requires consideration of the angular structure of the field of outgoing radiation (known at the present time) for more exact definition. When radiational measurements are obtained which differ in angular resolution, they can be compared and their agreement checked. The relative measurement error of the AK apparatus is approximately 5%.

The scientific apparatus performing these functions can operate in cycles of varying length. It is switched on by a special programmed device or on command from the Earth.

The successful launching of the "Cosmos 122", "Cosmos 144" and "Cosmos 156" satellites has made it possible to engage in practical transmissions for weather services, including TV information on clouds; this sort of information has been distributed widely by the USA in recent years, in conjunction with their construction of meteorological satellites, along with the results of decoding the IR pictures of the clouds and measurement data on the outgoing radiation, reflected and radiated by the Earth-atmosphere system. The volume of transmission for all observations was greatly expanded with the development of the "Meteor" system. This is certainly an outstanding achievement of Soviet science and technology.

Some Results of the Analysis of Satellite Information

A preliminary analysis of the materials obtained by means of the "Cosmos 122", "Cosmos 144", and "Cosmos 156" satellites has already shown that the shapes of the cloud formations, their structures, and image brightness are characterized by considerable variation. The structures of the cloud fields show features which cannot be tracked from ground meteorological stations, with the limited field of view of the observer. Both the TV and IR pictures usually allow a reliable discernment of large-scale cloud systems, related to cyclones, hurricanes, typhoons, atmospheric fronts, and zones of intertropical convergence, as well as fields of air-mass clouds. In these cloud systems it is usually the mesoscalar features of their structure which are studied: cloud bands of various sizes, usually elongated in the direction of the wind at the level of the clouds, convective cells of various shapes, consisting of cumulus, stratocumulus, alto-cumulus, and (in many instances) cumulo-nimbus and others.

The nature of the structure of the cloud field, the shape of the cloud formation, and the brightness of their images on the pictures usually permit conclusions to be drawn regarding not only the position but also the state evolution of corresponding synoptic objects and air masses. Thus, for example, on the basis of the unique vortical structure of the clouds which is typical of cyclones, hurricanes, and typhoons, we can estimate the stage of their development; from the width of frontal cloud bands, as well as the structure and brightness of their images, we can gain some idea of the activity of atmospheric fronts and the development of wave disturbances in them. By studying the shape of the clouds and the nature of the spatial distribution of cloud elements, we can estimate the wind, the type of air mass, and its temperature stratification.

In the TV pictures, it is possible to distinguish mesoscalar features of the distribution of air-mass clouds, connected with features of the local relief and thermal inhomogeneities of the subjacent surface. Thus, for example, orographic cloud belts are observed on the leeward side of mountains, repeating the main folds of the mountain ridges, and the effect of large islands and lakes, the air circulation on seacoasts, etc., on the distribution of clouds can be followed. The IR pictures taken at night and in the daytime are practically identical in contrast, and the possibilities of distinguishing between different types of clouds on the basis of these pictures are about equal.

During weather when few clouds are present, the difference in the reflectivity and temperature of different sections of the subjacent surface makes it possible fro the TV and IR photographs to distinguish dry land from water, to see coastlines, the valleys of large rivers, the limits of unbroken sea ice, snow-covered mountain massifs, etc.

On the basis of radiational observations in each of the spectral ranges (0.3-3, 3-30, and 8-12 μ), it appears possible, at least in middle and low latitudes, to discern large-scale dense cloudiness and regions where there are few clouds. The results of measurements in the spectral ranges of 3-30 and 8-12μ may be used for these purposes both day and night; in the "transparent window" at 8-12μ, they allow an approximate estimate of the height of dense clouds, thus considerably improving information on cloud cover. Since the majority of elongated cloud systems are related to cyclones, atmospheric fronts and zones of intertropical convergence, the radiation data reflect these objects as well.

The analytical results also indicate that the simultaneous reception of TV and IR pictures of cloud cover and the measurement of outgoing radiation from oriented satellites is of considerably greater value for studying weather conditions and atmospheric processes than the reception of individual TV photographs of cloud cover on the illuminated side of the Earth. By significantly improving and supplementing one another, these reports make it possible to estimate more reliably the synoptic conditions and the nature of the development of atmospheric processes. This information is of primary importance for an analysis of atmospheric processes and weather conditions above regions which are insufficiently accessible to conventional meteorological observations. It is also suitable for analysis in regions with a dense network of meteorological stations, since it allows corrections to be made in the analysis of weather charts.

Analysis of Satellite Information

The use of satellites in the interests of the weather bureau requires the organization of a ground system for the collection analysis and distribution of satellite information. The first step in the scientific research and experimental design aspects of the building of such a system, based on its application under practical conditions, was completed in 1966. The method which was devised and the ground facilities for the reception and analysis of information were tested and put into experimental use in conjunction with the meteorological satellites "Cosmos 122", Cosmos 144", and Cosmos 156". Let us pause briefly to discuss this system.

At the ground receiving sites, the TV and IR information is recorded on magnetic tape and film simultaneously; AK information is recorded only on magnetic tape.

Analysis of the pictures recorded on tape includes the following:

(a) Preparation of photographs and photo montages.

(b) Decoding, geographical and chronological matching of images.

(c) Decipherment of cloud-cover pictures.

(d) Compilation of schematic charts of cloud cover (nephanalysis charts), suitable for transmission over facsimile lines.

(e) Compilation of letter-number telegrams based on nephanalysis chart data, suitable for telegraphic transmission.

Special projection tables (illuminated stands) and previously prepared transparent graph paper and blanks with a grid of geographical coordinates for conversion are used for decoding and geographical matching of the TV pictures. At the same time, a special electronic apparatus has been devised and tested for performing these operations. This apparatus consists of a local television system, whose scan is controlled by an analog computer. The input from the tape recorder receives a video signal, recorded during the communication session with the satellite, as well as data on the angular orientation of the satellite, the flight altitude, and the coordinates of points below the satellite. At the output, the pictures emerge with a superimposed grid of geographical coordinates, free of perspective distortions and converted to a single scale. From these pictures, which are very suitable for comparison with synoptic charts, it is easy to compile photo montages. A fragment of such a photo montage is shown in Figure 2.

A geographical grid in the form of meridians and parallels, previously prepared with the aid of an electronic computer, is used for decoding and geographic matching of the IR pictures. This grid can be superimposed photographically on the picture.

The problem of deciphering the cloud cover from the photographs is viewed as a problem in image identification; under the conditions of practical work, it is solved qualitatively. The basis of this method is the differences in brightness, size, and structure of the cloud images and objects on the subjacent surface. The overall synoptic situation and apparatus parameters are also taken into account. By studying the tone and structure of the image by means of its visual analysis, the photographs are used to determine the boundaries of the cloud fields and to determine the different characteristics of the clouds (shape, number, structure, etc.). The characteristics of the clouds are represented on the nephanalysis charts by conventional symbols. Examples of nephanalysis, together with the pictures related to them, are shown in Figures 3 and 4.

The measurement data from the AK apparatus are analyzed with the aid of a computer. The program of machine analysis provides for the matching of the measurement results with the time and geographical coordinates, converts the

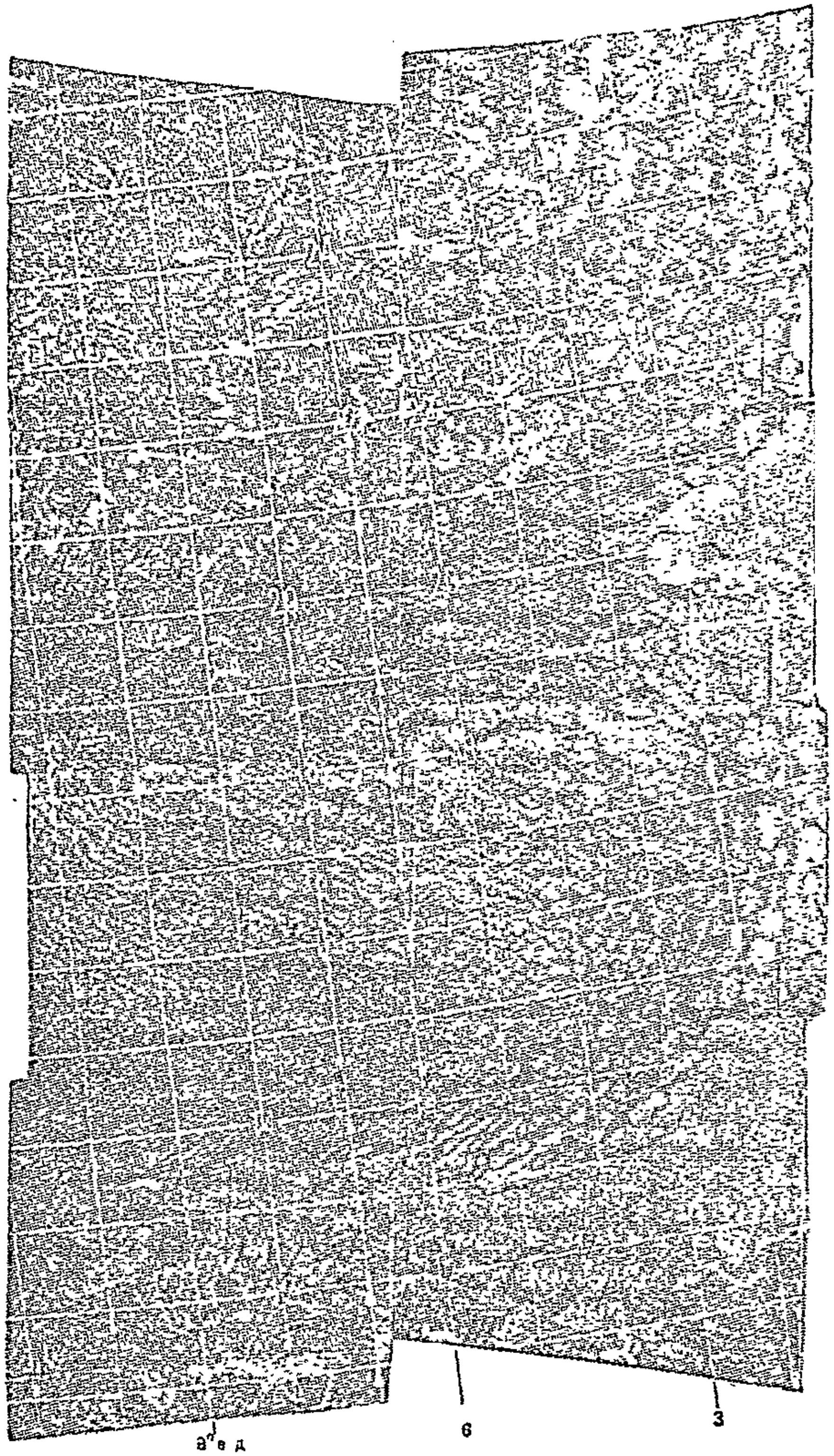

Figure 2. Photo Montage of Decoded TV Pictures. "Cosmos 144", 9 April 1967, 1327 hours (Moscow Time).

measurement data into physical values, and gives out the results. The results of the analysis appear in the form of numbered charts of radiation temperature (on the basis of 8-12μ measurements) and the intensities of reflected (0.3-3) and emitted (3-30 μ) radiation. The charts are supplied with a grid of geographical coordinates automatically superimposed on them. The technique of further analysis of these charts is analagous to the technique of the analysis of terrestrial and upper-air weather charts. Sections of radiation charts are shown in Figure 5, 6, and 7. On these charts, the radiation temperature is given in °C; if the temperature is negative, the number 40 is added to its absolute value. The intensity of the reflected and emitted radiation is given in calories/cm^2·min·steradian·10^2. The time (hours and minutes) is printed on the number charts, to the left of each line. The radiation charts are produced with isolines drawn on them for transmission over facsimile lines.

Analagous algorithms and programs have also been prepared for the computer analysis of the measurement data from the IR apparatus.

The analyzed information is collected at the Hydrometeorological Center of the USSR, from where it is transmitted to subdivisions of the weather bureau both in the Soviet Union and abroad.

The completion of the first stage of work in the construction of a system for collecting, analyzing, and distributing satellite information is an important contribution to the solution of the problem of the complex automation of the Hydrometeorological Service of the USSR. Effective use of the satellite information will be made possible by the further development and expansion of this system, based at the Hydrometeorological Center of the USSR at Moscow and


30° South Latitude
47° East Longitude
South Latitude
East Longitude

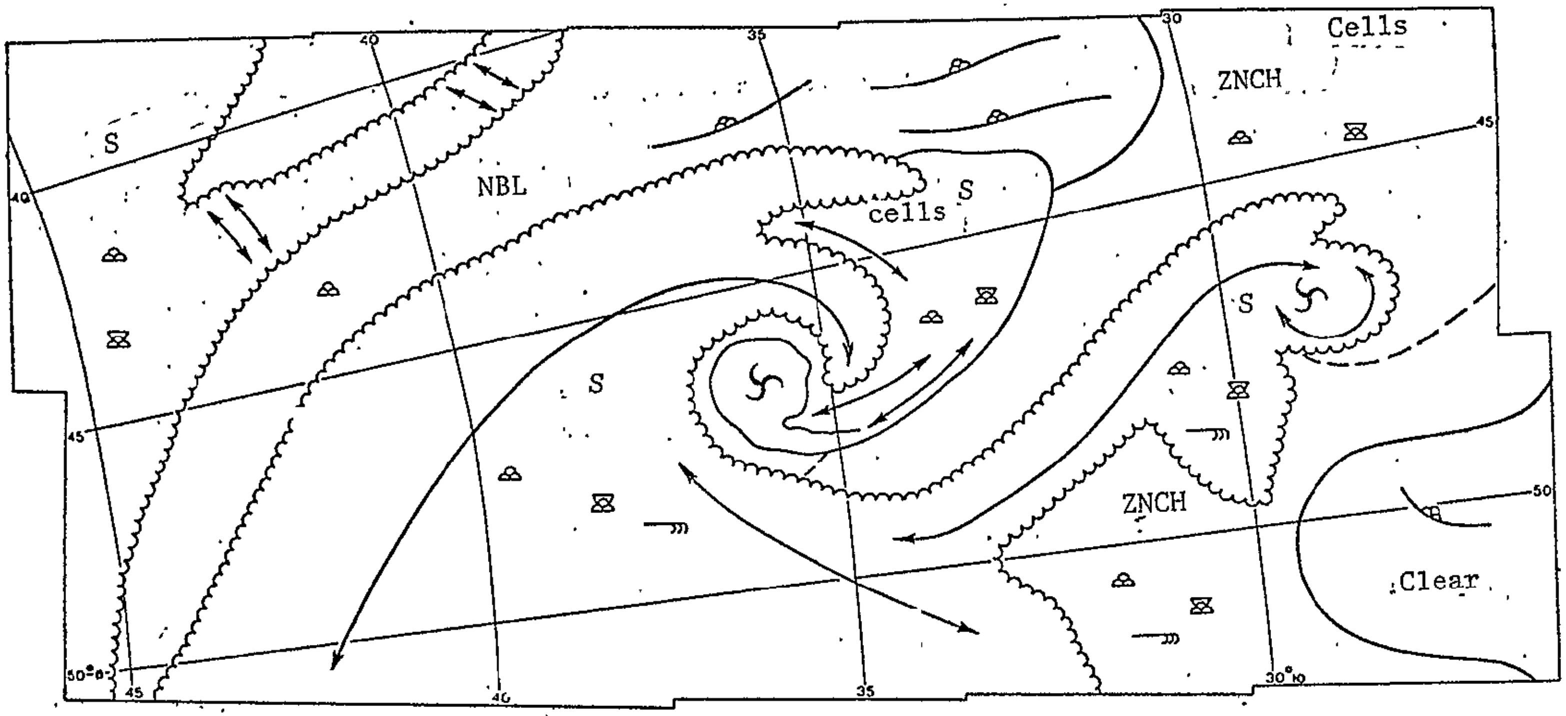

Figure 3. Nephanalysis and TV Picture of Clouds. "Cosmos 144", 31 March 1967, 1121 hours (Moscow Time).

[Tr. Note: ZNCh, NBL, and S are arbitrary symbols not defined in text]

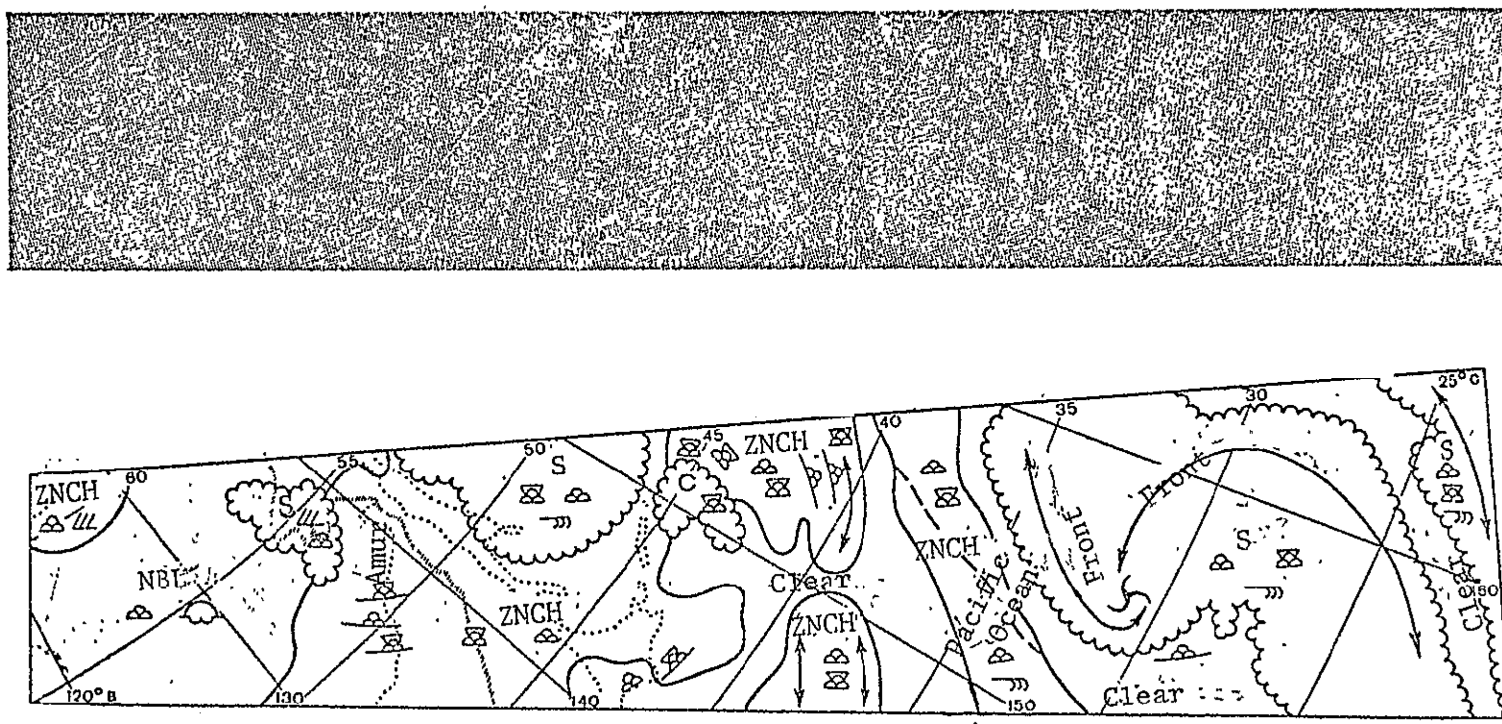

Figure 4. Nephanalysis and IR Picture of Clouds. "Cosmos 122", 15 September 1966, 1837 hours (Moscow Time.

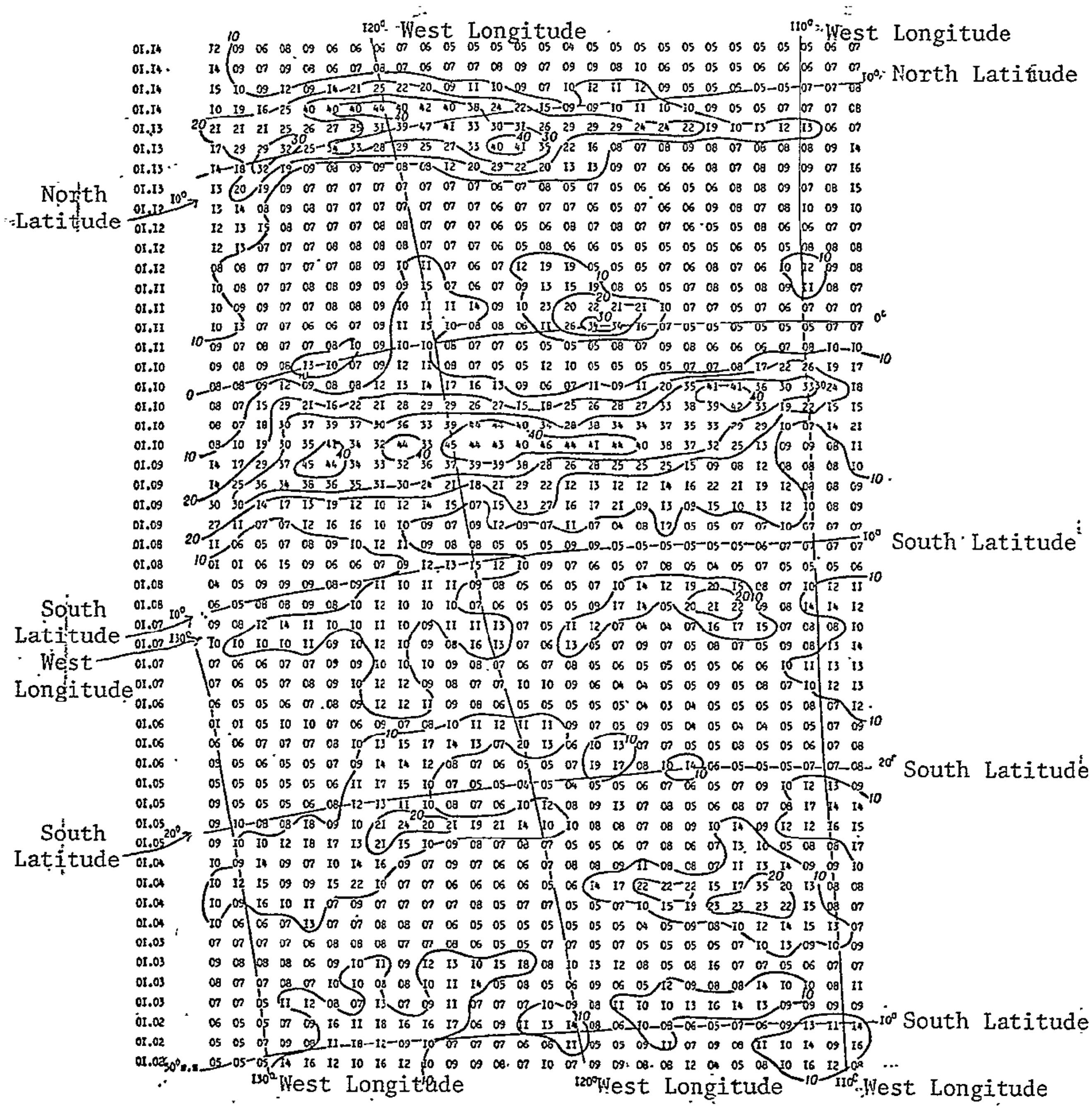

Figure 5. Chart of Intensity of Reflected Short-waves Radiation (on the Basis of Measurements in the 0.3 - 3u Region). "Cosmos 144", 14 March 1967.

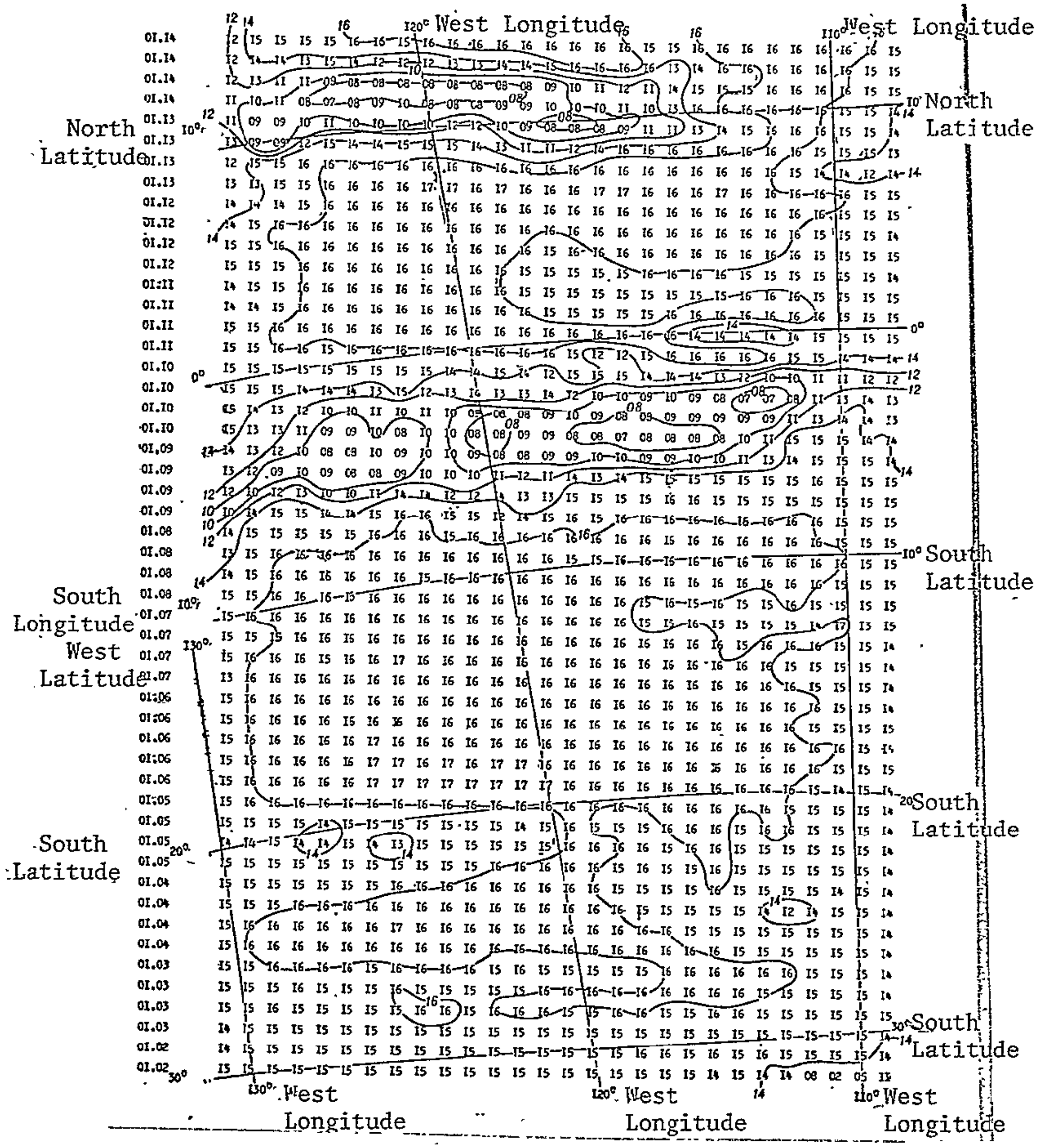

Figure 6. Chart of Intensity of Long-wave Radiation (on the basis of measurements in the 3-30μ region). "Cosmos 144", 14 March 1967.

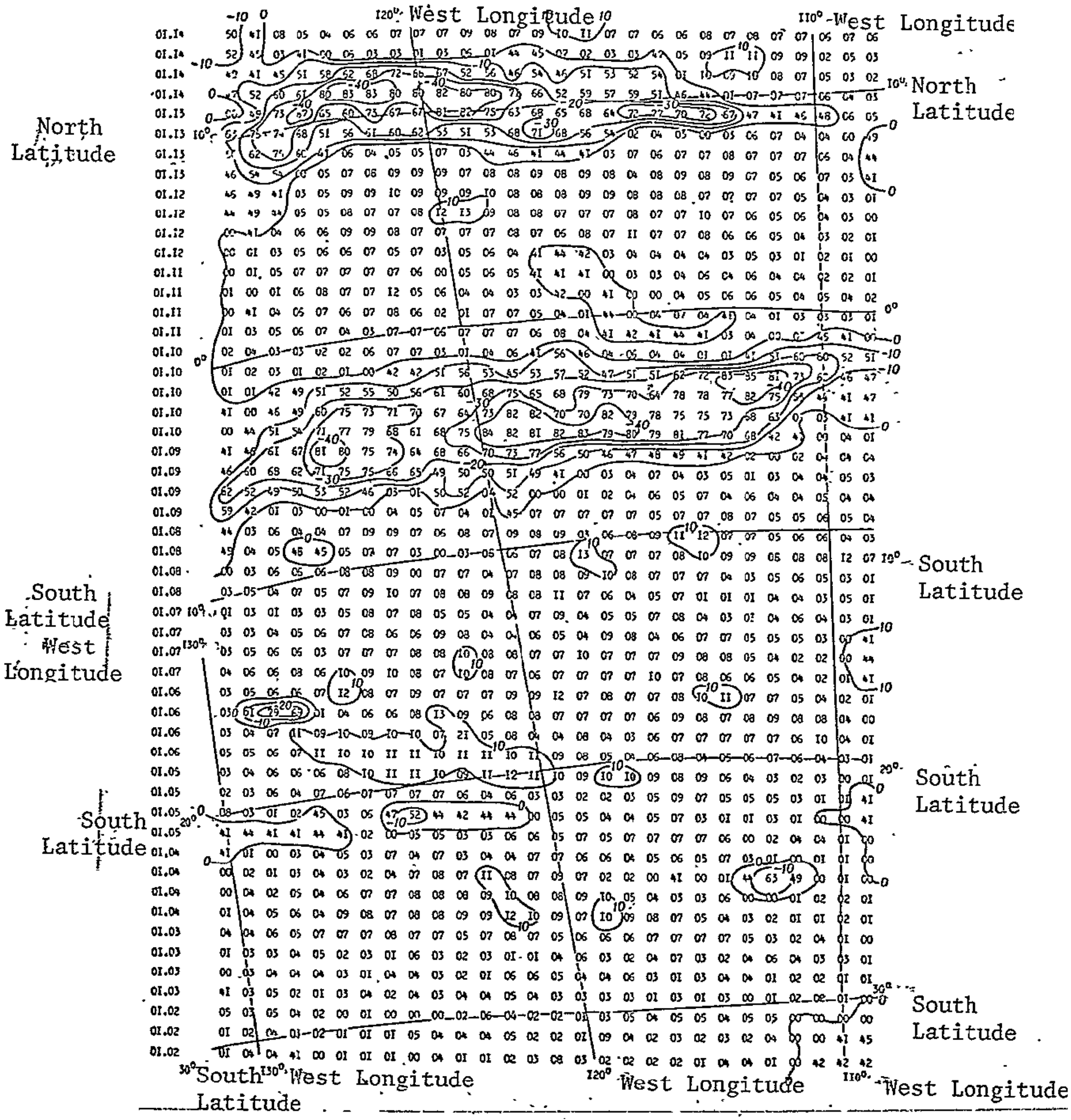

Figure 7. Chart of Radiational Temperature (on the basis of measurements in the 8-12μ region). "Cosmos 144". 14 March 1967.

the regional meteorological centers at Novosibirsk and Khabarovsk, which will serve at the same time to collect, analyze and distribute the data from terrestrial observations. The possibility of joint analysis at these centers allows more exact definition of the data from satellite and terrestrial observations, and an improvement of the quality of their analysis on this basis. Local subdivisions of the weather bureau, lacking the means and apparatus for receiving and analyzing the information, will receive prepared, jointly analyzed and correlated observational data.

Experiment in Photographing Clouds from the High-Orbital Communications Satellite "Molniya I"

To explore the possibility of observing clouds from high-orbital satellites (height of orbit = 30,000-40,000 km), experiments in making TV pictures of the earth were conducted, using the "Molniya I" communications satellite. This satellite carries a system of accurate orientation and relay apparatus, which allows solution of the problem of television observation of clouds, along with provision for performing its basic task, that of long-range communication. The photographs of the earth are made with the aid of a special television apparatus, whose cameras have two interchangeable objectives: one is a wide-angle lens, the other is a narrow-angle lens. The wide-angle objective is intended for obtaining generalized pictures of the cloud cover. From an altitude of 30,000 - 40,000 km, the earth occupies only a portion of its field of view. The narrow-angle objective is used for obtaining more detailed pictures of the clouds above individual regions of the globe, with radii up to 8000 km.

The television cameras take pictures in the yellow-red regions of the spectrum, which considerably reduces the brightness of the atmospheric haze at the same time that it enhances the quality of the clouds and the Earth's surface. A set of light filters of various densities allows observations to be made of areas of the Earth with the Sun at various altitudes. A special tracking system mounted in the satellite keeps the TV cameras trained on the Earth.

At the ground stations, the TV information from on board the satellite is received through a relay system operating in a direct transmission regime. The pictures which are received are recorded on photographic film. By viewing them simultaneously on the screens of the TV monitors, the photography regime can be controlled.

Analysis of the TV pictures received with the aid of the "Molniya I" satellite has shown that these pictures can be used to gain an idea of the distribution of small-scale cloud systems, which determine the nature of the weather over large territories. In the pictures taken with the narrow-angle objective, it is possible to distinguish between vast cloud vortices, which have a characteristic spiral shape, the broad cloud bands of atmospheric fronts, etc.

Experiments in receiving meteorological information from high-orbital satellites are very important in selecting the orbits of satellites in future meteorological systems in space. These experiments help us to decide whether it is advantageous for meteorological purposes to employ a system which consists of both low-orbital and high-orbital satellites.

Use of Data from Satellite Observations

Observations of the Earth's atmosphere from space, carried out from satellites, are qualitatively new and unusual for meteorologists. Certain items of information (for example, data on the radiation balance and its components) have never been employed in the practical work of analyzing and forecasting the weather. Therefore, a certain period of time is required for the collection and detailed study of materials from satellite observations, for the purpose of working out methods of interpreting them and using them effectively at the weather bureau.

In recent years, studies have proceeded rapidly and experience has been gained in the interpretation and practical use of satellite information on clouds. Some results have also been gained in the field of interpreting and putting into practical use, the data from measurements of outgoing radiation. These studies have been carried out widely in a number of the scientific research departments of the Hydrometeorological Service of the USSR and other agencies.

In the studies of the interpretation of satellite information on clouds, received in picture form, considerable attention has been devoted to the identification of the clouds in the pictures and to the determination of their characteristics, used directly in the analysis and forecasting of the weather. One of the first topics studied was the possibility of determining the shapes of clouds and their numbers. The great significance of this task of picture interpretation is clearly evident. Merely by using the pictures to create the actual image of the spatial distribution of the clouds and to study their shapes in detail, it is possible to draw valid conclusions regarding the state of the atmosphere and the processes taking place in it. As we pointed out earlier, the problem of identifying clouds and determining their characteristics on the basis of the TV and IR pictures has been solved qualitatively by the visual analysis of these pictures.

The technical capabilities of the TV and IR apparatus mounted in satellites do not allow distinctions to be made in the pictures regarding a number of details, which are presently employed in the international classification of clouds. The differentiation of various types of clouds, even in the TV pictures which have a higher resolution in comparison with the infrared ones, is possible only by studying them very carefully and calls for considerable experience. In the pictures, those details whose dimensions are smaller than the size of the unit of resolution are usually flattened out, especially if these details differ slightly from the surrounding background in their radiation and reflection characteristics. In distinguishing the shapes of clouds in pictures, it is also important to estimate the altitudes of their lower limits, the nature of precipitation, etc. Therefore, it is suitable to use for the TV and IR pictures a less detailed classification of clouds, one which divides them into four groups: stratus, cumulus, cumulo-nimbus, and cirrus. This classification is based on the differences in brightness, size, and structure of the cloud pictures. To determine the number of the latter on the basis of the TV pictures, four gradations are used (8-10, 5-8, 2-5, and 0-2 scale divisions), although the technical capabilities of the TV apparatus in the "Cosmos" satellites makes it possible to distinguish five gradations (10, 7-9, 4-6, 1-3, and 0 scale divisions). Using the IR pictures, the number of clouds is determined on the basis of three gradations (7-10, 4-6, and 0-3 scale divisions).

The photographs of clouds have the advantage over discrete ground observations that they give a complete picture of the distribution over rather large territories. This makes it possible to divide the groupings of the cloud formations into distinct complexes in the pictures, i.e., to study structural details of cloud fields of different sizes. In decoding the pictures the geometrical features of the structure show up on two scales, the mesostructure and the macrostructure of the cloud field. The mesostructural cloud formations include groupings of cloud shapes into complexes having the appearance of bands, chains, cells, etc., whose dimensions do not exceed 100 km in cross section. Larger-scale groupings of clouds, constituting combinations of mesostructures, are related to macrostructural cloud formations. These are the cloud vortices of cyclones, having the appearance of concentric bands and spirals, frontal cloud systems, various parts of which (to one degree or another) usually form distinctive bands, immense gatherings of clouds in zones of intertropical convergence, etc. Meso- and macrostructural features of a cloud field, as analyzed in nephanalysis, convey definite indirect information on the dynamics of atmospheric processes. The meteorologist who has at his disposal the picture of the clouds or the nephanalysis prepared on the basis of this picture actually becomes an experimental physicist, studying the motion of gases under laboratory conditions with the aid of a suspended substance. The difference consists only in the fact that the size of the "Laboratory" of the synoptic meteorologist is measured in millions of square kilometers, and the role of the suspended matter is played by the clouds. Dynamically significant features in the cloud field, revealed in nephanalysis, simplify the process of using cloud information. Experience in compiling nephanalysis charts has shown that the results of decoding, containing the indicated characteristics of the cloud field, are of considerable help in analysis and forecasting.

The methods of decoding and the forms in which the decoding results are given are being improved rapidly at the present time. Studies in this direction are aimed at recovering from the photographs of clouds, as great a complex of information as possible which is required for analysis and forecasting of the weather, and for the expression of the information in a form suitable for use in practical work and in scientific investigations, as well as for transmission over communication lines. Since the principal communications media used by the weather bureau are the facsimile and telegraph lines, the basic form for transmission of satellite information regarding clouds in recent years has remained the facsimile nephanalysis chart. For regions where the facsimile lines do not exist, in case of necessity the data on these charts can be sent by telegraph in the form of a letter-number code. Satellite observations of cloud cover will also be included in the materials from analysis of ground data, issued in the form of charts of conventional observations.

The qualitative methods of decoding used for compiling nephanalysis charts are very time-consuming and are subject to subjective interpretation. It is therefore extremely timely to devise objective methods of decoding the cloud pictures with the aid of a computer. From the contemporary standpoint, for an objective decoding process, an important position will be occupied by studies of the application of statistical analysis to the fields of reflected and emitted radiation from the subjacent surface. The significance of the satellite information in picture form regarding the clouds is not limited, however, to the possibility of studying the distribution of clouds over the Earth's surface, which is itself very important for detemrining actual weather conditions. The shapes and structures of cloud formations, their evolution and modification, reflect a dense complex of physical processes occurring in the atmosphere. Depending on the nature of these processes, the pictures will show different views of the cloud distribution. This fact makes it possible to use these pictures for evaluating a synoptic situation and determining the distribution and evolution of a great many other parameters of the state of the atmosphere, which are not measureable directly from satellites. In particular, there is an opportunity to determine the statistical relationships between the spatial structure of the cloud field and the fields of such meteorological elements as humidity, pressure, wind (its horizontal and vertical components), and precipitation.

The statistical characteristics obtained in this manner will give the spatial distribution of the above-mentioned meteorological elements for specific cloud formations, observed with the aid of satellites. This provides the possibility of establishing, for a certain cloud field, the atmospheric parameters of interest to us in regions where the network of meteorological stations is extremely thin. The values of the meteorological elements established in this manner can be employed jointly with instrument measurements carried out by the ground network of meteorological and aerological stations, for the interpolation of values at the centers of the regular network, used in systems of computerized weather forecasting. In addition, statistical relationships of a similar type can also be used directly in an analysis of the synoptic situation.

Proceeding on this basis, the possibilities are being studied of using cloud pictures for:

(a) Determining the positions and stages of development of cyclones, hurricanes, and typhoons;

(b) Definition of the position and activity of atmospheric fronts and zones of intertropical convergence;

(c) Appearance of fields of large-scale vertical movements;

(d) Improved analysis of pressure fields and wind, including jet streams;

(e) Estimates of the nature of the temperature stratification of the atmosphere and the humidity of the air;

(f) Estimates of the effect of features of the local relief and thermal inhomogeneities of the subjacent surface on the distribution of the clouds, etc.

As of the present time, a number of practical results have already been obtained which make it possible to improve the conventional synoptic analysis by qualitative methods. Physical and statistical methods have been used to show the possibility of establishing, on the basis of data on clouds, fields of large-scale vertical movements, the geopotential of the surface at 500 mb, and the wind at the level of this surface.

The basis of these methods is the concept that between the vertical component of the speed vortex and the divergence on the one hand the numbers and shapes of the clouds on the other, there must be some correlation. Relationships of this kind were obtained for various combinations of shapes and numbers of clouds and are used for establishing the above-mentioned parameters at centers in the regular network. If we know the value of the vortex of speed and divergence above some portion of the globe and have data on the wind at the boundary of the region in which we are interested, it is easy to calculate the direction and speed of the wind at any point in this region.

Using standard methods, it is then possible to shift to the field of the geopotential from the field of the wind.

The preliminary results which have been obtained have given a completely satisfactory picture of the field of the wind and geopotential which are established.

However, these results have not yet been put to practical use. Further developments of these studies will have great significance for improving both the synoptic and objective analysis of fields of meteorological elements with the aid of a computer, especially for sparse, conventional observations of certain regions.

At the same time, studies are in progress which deal with the possibility of using satellite data on clouds in computerized forecasting systems. In such systems, they can be used as sources for the forecasting of the clouds themselves and the phenomena accompanying them, as well as for predicting fields of meteorological elements related to the clouds by certain relationships. The methods of solution for these problems are still tentative. The basic difficulty is caused by the lack of an exact quantitative estimate of many factors involved in cloud formation. In order to include observations of clouds in computerized forecasting systems, it will be still necessary to carry out a great deal of scientific research, especially in the physics of cloud-formation processes. A correct theoretical description of the evolution of cloud systems in forecasting systems will naturally improve weather forecasting and is a big step forward in the direction of setting up reliable methods of predicting the weather.

As far as the use of data on radiational observations made from satellites is concerned, at the present time there are two basic procedures. In the first of these, the results of these observations, as well as data on the clouds, are used to evaluate the synoptic situation and to determine the distribution and evolution of a number of parameters of the state of the atmosphere, required for analysis and forecasting of the weather. The second procedure assumes the determination from measurement data of the outgoing emission in the radiation balance and its components, with the goal of considering them in systems for analyzing and forecasting the weather.

Inasmuch as the required role in the formation of fields of outgoing radiation is played by the clouds, the investigations in the first procedure are concerned primarily with the problem of identification of cloud fields by using data from radiational observations. The state of the atmosphere and the processes occurring in it are then estimated on the basis of the results of a diagnosis of the features of these fields. With regard to the reflected and emitted properties of clouds, at the present time there are studies in progress which deal with the problem of determining (on the basis of data from radiational observations) the position and activity of atmospheric fronts and zones of intertropical convergence, as well as the possibility of cyclones and anti-cyclones. Experience in compiling charts of the intensity of reflected and emitted radiation, as well as the radiational temperature of the basis of measurements conducted with the "Cosmos 122", "Cosmos 144", and "Cosmos 156" satellites, has shown that these charts usually make it possible to improve the synoptic analysis of atmospheric processes.

From the standpoint of the second procedure for investigation, the value of the data on the outgoing radiation consists in the fact that they can be used for a quantitative estimate of several characteristics of clouds. Means have already been suggested for determining the height of the upper limit of the clouds and estimating their numbers on the basis of measurements of radiation in the 8-12μ spectral range. Mention has already been made of the possibility of estimating the stratification of clouds on the basis of a joint analysis of the results of radiation measurements in various regions of the long-wave spectrum. Data from measurements of outgoing radiation in the spectral range from 8-12μ could also be used in statistical analysis to estimate the vertical distribution of temperature and humidity in the atmosphere. The application of quantitative methods to the diagnosis of cloud fields and various parameters of the state of the atmosphere, with incorporation of observational data from observations of outgoing radiation, will undoubtedly expand the possibilities of using all material from satellite observations.

In the studies in the second procedure, special attention has been devoted to the use of the data from radiational observations in systems of computer forecasting, considering the heat flow, as well as in statistical methods of weather forecasting. The perspectives for the development of these studies are still only in the planning stages. Calculations have been made of changes in the temperature and the geopotential of isobaric surfaces at various levels of the atmosphere due to the radiational heat influx, which is determined by certain values of temperature and humidity. Such estimates have shown that the role of radiational heat currents in the change of temperature and the geopotential of isobaric surfaces is significant in a number of cases. The possibility has been mentioned of establishing statistical links, suitable for use in long-range forecasting, between the meteorological parameters which can be determined from observations from satellites, and the characteristics of future weather. Methods have been proposed for using data on the radiation balance and its components for determining the radiational heat flow for the purpose of consideration in nonadiabatic systems of computerized forecasting. However, these methods have still not been tested sufficiently in practical use.

In order to include the data from radiational observations in systems of computerized forecasting, there still remains the task of performing a great many scientific research experiments in the interpretation of these observations. A very important role in this regard will be played by the analysis of methods of transition from the readings of the instrument transmitters mounted on the satellites to physical values which are of interest from the standpoint of their inclusion in the forecasting system. It is necessary first of all to test and improve the means of conversion from the readings of the transmitters of the narrow-range AK instruments, which measure the intensity of the radiation from small areas of the Earth's surface at very diverse angles, to the values of the radiation flow through a horizontal area at the upper limit of the atmosphere. Such a transition can be made only in the case where the angular distribution of the outgoing radiation under actual conditions is known.

In recent years, for the purpose of clarifying the angular distribution of radiation, wide use has been made of its calculations in various segments of the spectrum for different models of the atmosphere, also including actual synoptic positions. Calculations of the outgoing short-wave radiation have allowed estimation of the effect of the disturbed lower layers of the atmosphere on the value of the outgoing short-wave radiation, as well as clarification of the role of the basic factors on which the change of its angular distribution depends. In their turn, calculations of the outgoing long-wave radiation have made it possible to draw conclusions regarding the degree of the effect of various factors which characterize the state of the atmosphere and the subjacent surface, on the variability of angular distribution of the outgoing long-wave radiation in various segments of the spectrum. Checking and improvement of these results in materials obtained from satellites makes it possible, in practical analysis of satellite information together with charts of the intensity of reflected and emitted radiation, to plot charts of the radiation balance and its components.

The charts of the radiation balance and its components can themselves be of great value for the analysis and prediction of the weather. On the basis of these, it is possible to study the distribution and evolution of sources and flows of heat, acting on the evolution of thermobaric fields in the atmosphere. Investigation will also be conducted to explain the relationship between the radiation balance and the characteristics of atmospheric circulation, which are important for purposes of long-range weather forecasting. However, for the use of data on charts of the radiation balance and its components in systems of computerized forecasting, it still remains to be solved the very important problem of determining the radiant heat influx.

At the present time, methods have been devised for an approximate estimate of the total value of the radiant heat influx for the entire thickness of the atmosphere, according to data on the flows of outgoing radiation. However, it does not solve the problem of computerized forecasting even in the case of using the simplest one-level systems. At the present state of these problems, the heat influx must be determined at each stage in time for different layers of the atmosphere. From the above, it is quite clear that the development of computerized forecasting systems which will correctly measure the radiant heat influx on the basis of satellite observations of outgoing radiation will require considerable expansion. Of great importance to these goals will be the studies of the physics of radiation processes in the atmosphere, the study of the structure of the spatial distribution of the radiation flows, and their links to the radiant heat flow at various levels of the atmosphere.

It would not be incorrect to say that on the basis of the scientific research projects currently in progress on a broad front in the field of satellite meteorology, the accuracy of weather forecasting will be increased, as well the effectiveness of the meteorological service.